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The OSD, Central Test and Evaluation Program (CTEIP) is tasked to provide a coordinated process for making joint investments in defense T&E to offset the challenges presented by declining investments in test assets and increasing test requirements. Under CTEIP sponsorship, the Navy and Air Force are jointly developing three Joint Installed System Test Facility (JISTF) enhancements that are based on dynamic virtual reality simulation technology. The three enhancements are the Infrared Sensor Stimulator (IRSS), Generic Radar Target Generator, and Joint Communications Simulator. The JISTF installations will occur at the Air Combat Environment Test and Evaluation Facility, NAWCAD Patuxent River, Maryland, and the Avionics Test and Integration Complex, Air Force Flight Test Center, Edwards Air Force Base, California. These enhancements will provide each ISTF with the capability to simultaneously test multiple avionics and sensor subsystems installed on an aerospace System Under Test (e.g., manned and unmanned aircraft) in a ground test environment. The ISTF enhanced test capabilities will be used to evaluate multisensor data fusion/correlation and subsystems' interoperability for IR sensors, RADAR, GPS, and Communications and Data Link subsystems.

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Infrared scene projector system design description for installed infrared sensor testing in an anechoic chamber environment

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ABSTRACT

The Office of the Secretary of Defense (OSD), Central Test and Evaluation Program (CTEIP) is tasked to provide a coordinated process for making joint investments in defense test & evaluation (T&E) to offset the challenges presented by declining investments in test assets and increasing test requirements. Under CTEIP sponsorship, the Navy and Air Force are jointly developing three Joint Installed System Test Facility (JISTF) enhancements that are based on dynamic virtual reality simulation technology. The three enhancements are the Infrared Sensor Stimulator (IRSS), Generic Radar Target Generator (GRTG), and Joint Communications Simulator (JCS). The JISTF installations will occur at the Air Combat Environment Test and Evaluation Facility (ACETEF), Naval Air Warfare Center, Aircraft Division (NAWC-AD), Patuxent River, MD and the Avionics Test and Integration Complex (ATIC), Air Force Flight Test Center (AFFTC), Edwards Air Force Base, CA. These enhancements will provide each ISTF with the capability to simultaneously test multiple avionics and sensor subsystems installed on an aerospace System Under Test (SUT) (e.g. manned and unmanned aircraft) in a ground test environment. The ISTF enhanced test capabilities will be used to evaluate multi-sensor data fusion/correlation and subsystems' interoperability for Infrared Sensors, RADAR, GPS, and Communications and Data Link subsystems.

This paper addresses a modular cost-effective Infrared Scene Projector (IRSP) system that will be used by the IRSS to stimulate *installed* Infrared (IR) Electro-Optic (EO) sensors undergoing integrated developmental and operational testing. The IRSP system has been designed for testing IR/EO Sensors in either an anechoic chamber and hangar environments. The IRSP consists of the following major functional subsystems: Control Electronics Subsystem (CES), Infrared Emitter Subsystem (IRES), Projection Optics Subsystem (POS), Mounting Platform Subsystem (MPS) and Non-Uniformity Correction Subsystem (NUCS). The CES uses IR imagery input and generates the appropriate digital/analog signals to drive the IRES. The IRES contains the micro-resistor array, which acts as the wide-band dynamic source of IR energy. The POS projects the IRES energy into the entrance aperture of the sensor via mechanical alignment by the MPS. The MPS also provides Radio Frequency (RF) shielding thereby enabling simultaneous IR/RF testing in an anechoic chamber. The NUCS measures the radiometric properties of the IRES off-line; and the resulting data is used for real-time correction via the CES. The IRSP is designed for testing the following types of sensors: Forward Looking Infrared (FLIR), Infrared Search and Track (IRST), Missile Warning Systems (MWS), Missile Launch Detectors (MLD), and IR Missile Seekers. The stimulation's spatial, temporal, spectral, and radiometric requirements vary significantly for the individual sensor types under test. Accordingly, the IRSP configuration will be modular in order to provide the capability to adapt to the variety of specified sensor requirements with a minimum amount of asset duplication. Adaptation to a specific sensor will require switching or modifying the POS, MPS and possibly the NUCS. A detailed system design description of this IRSP is provided along with the stimulation requirements for the identified sensor types.

Keywords: Installed Systems Test Facility, Hardware In The Loop, Infrared Scene Projection, Stimulation, Simulation

1. BACKGROUND & INTRODUCTION

Since the early 1980's, there has been a strong worldwide interest in the development of technologies that would enable HardWare In the Loop (HWIL) stimulation of Imaging Infrared (I^2R) sensors. There are numerous competing candidate technologies[13], of which, two (2) remain as viable alternatives. These two technologies are Infrared (IR) emitting micro-resistor arrays[7,8,10] and IR laser diode arrays[6]. Each technology has both advantages and disadvantages that are dependent on the specified application. Presently, a majority of the image projection systems are based on micro-resistor arrays. Initially, micro-emitter array technologies required large development efforts that limited their use to select government research and testing laboratories. Recently micro-resistor arrays are being offered as packaged commercial products and are starting to be incorporated at the sensor development facilities (e.g., weapon system prime contractors). The IRSP technology discussed in this paper is a 512x512 micro-resistor array produced by Santa Barbara Infrared (SBIR) and Indigo Systems.

All IRSP's are configured to accomplish the same purpose, e.g., *"To stimulate an I^2R sensor with dynamic projected radiometric energy to a sufficient level of fidelity; causing the sensor to react to the stimulation just as it would to the real-world conditions being simulated"*. Two fundamental capabilities are required to accomplish the foregoing validity objectives. First, the IR scene generation equipment must have the capability to create a valid simulation of the real-world conditions. Second, the IRSP must be capable of accepting the simulated scene, retain sufficient scene fidelity, and interface appropriately to the UUT. The subtleties of accomplishing these goals will be discussed in this paper.

A brief background discussion of IR scene generation follows. High quality IR scene generation will typically require extensive high-fidelity three-dimensional (3D) databases of targets, terrain, and in some cases atmosphere. The IR scene generation equipment must then apply the appropriate attributes to these database elements for high-fidelity IR scene rendering (i.e., the processes of creating two-dimensional (2D) images from the 3D databases given the simulation dynamics - viewpoint, resolution, frame rate, etc.). Over the years, real-time IR scene generation equipment has evolved from multi-million dollar custom hardware/software solutions to less costly more commercially based platforms (e.g., Silicon Graphics, Inc. OnyxII with Infinite Reality Engine Graphics). For the purposes of this paper, it is assumed that the IR scene generation capability is sufficient for the required test application. The remainder of this paper will focus on the IRSP. The IRSP will have the capability to accept scene images from a Scene Generation Subsystem (SGS), perform a resistor non-uniformity correction of each scene image pixel, and convert the image to the appropriate radiometric output. The output energy from the IRSP will be collimated and projected into the entrance aperture of the Unit Under Test (UUT).

This paper discusses two IRSP's that are being developed by the Navy IRSS Program Management Office and integrated by SPARTA, Inc. in support of the CTEIP JISTF IRSS Enhancement. The IRSP systems will be installed with the IRSS systems at the U.S. Navy Air Combat Environment Test and Evaluation Facility (ACETEF) located at the Naval Air Warfare Center, Aircraft Division (NAWC-AD), Patuxent River, Maryland, and the U.S. Air Force Avionics Test and Integration Complex (ATIC) located at the Air Force Flight Test Center (AFFTC), Edwards Air Force Base, California. The first IRSP will be used at the ACETEF for testing installed Forward Looking Infrared (FLIR) sensors in a hangar or anechoic chamber environment. The second IRSP will be for testing of installed Missile Launch Detection sensors in an ATIC anechoic chamber environment. The hanger atmospheric environment is expected to subject these subsystems to a mildly corrosive environment requiring exterior surfaces to be environmentally hardened for dust and humidity. The anechoic chamber environment will subject these subsystems to a broad spectrum of Radio Frequency (RF) energy requiring portions of these subsystems to be shielded for Electro-Magnetic Interference (EMI). There are future plans to develop a number of additional Infrared Scene Projectors (IRSP's) that will be used to test Imaging Infrared (I^2R) devices while installed on a variety of platforms (e.g., aircraft, helicopters, etc.) in a hanger or anechoic chamber environment. The distinction of these IRSP's relative to past developments is that these will be the first IRSP's designed for IR stimulation while the UUT remains installed on the weapon system platform. The remainder of this paper will focus on the design of the first IRSP which will used for FLIR testing.

2. SYSTEM DESIGN DESCRIPTION

The first IRSP, illustrated in Figure 2-1, is being configured initially to stimulate a rotary wing aircraft installed FLIR while in a hangar environment. It is beyond the scope of this paper to list all the requirements of the hangar configured IRSP. However, from a functional high-level standpoint this IRSP must be capable of performing the following functions:

- Accept as real-time input analog RS-170 video for demonstration purposes
- Accept as real-time input 16-bit Direct Digital Output for the OnyxII (DDO2) video
- Provide greater than 30 seconds of local IRSP playback of 512x512 16-bit imagery at 60 Hz
- Run the 512x512 array at a maximum frame rate of 200 Hz
- Project into two separate fields of view, with the capability to switch within 1.0 second
- Allow for optical alignment to the UUT
- Have sufficient radiometric dynamics to cover most operational environments of the UUT
- Contain all hardware/software necessary to correct resistor non-uniformity and provide calibrated radiometric output
- Provide a Windows NT platform running a Graphical User Interface (GUI) controlling all IRSP functions
- Provide a remote SGI IRIX GUI clone that controls the IRSP via Ethernet commands
- Have a modular configuration which permits future adaptation for stimulation of other UUTs
- Provides for future simultaneous RF/IR testing in an anechoic chamber

The basic design philosophy treats the IRSP as a transducer device. Accordingly, the IRSP converts the high fidelity IR scenes digital data to collimated radiometric IR radiation. The system is both modular and scalable to facilitate future plans to configure the system to test UUTs other than FLIR sensors. Therefore, the systems have been segmented into seven (7) fundamental modular subsystems, which are: the Control Electronics Subsystem (CES), Software Control Subsystem (SCS), Infrared Emitter Subsystem (IRES), Environmental Control Subsystem (ECS), Projection Optics Subsystem (POS), Mounting Platform Subsystem (MPS), and Non-Uniformity Correction Subsystem (NUCS). These subsystems are further described in the following paragraphs.

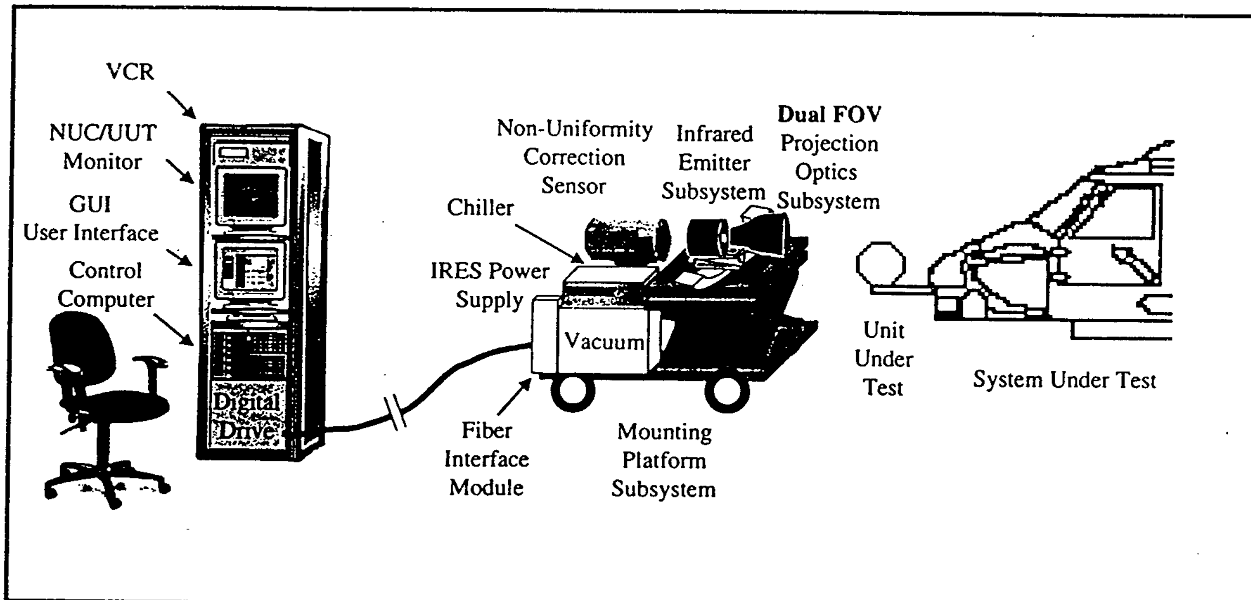

Figure 2-1. IRSP Hangar Configuration for FLIR Stimulation

2.1. Control Electronics Subsystem (CES)

The CES for this IRSP includes a Windows NT based Silicon Graphics Incorporated (SGI) Virtual PC computer processing platform and an SBIR VME based IRES control chassis. A Bit-3 PCI to VME interface is used to control the functions of the VME Circuit Card Assemblies (CCAs), allowing full control of the IRSP via software running on the SGI Virtual PC. Table 2.1-1 provides a detailed listing of each component of the CES along with its description and use(s).

Component	Description	Use(s)
Control PC	SGI WinNT Virtual PC Model 540 with: Two Intel 450 MHz Xeon Processors 2.0 GB RAM Six 64-bit PCI slots on Two Busses (4 on one and 2 on the other) Integrated Analog Video Input/Output (2 streams - NTSC, PAL, or S-Video) Integrated 10/100 Base-T Ethernet SCSI Hard, CDROM, Jazz, Zip, and Floppy Drives Two USB ports (one for the keyboard with integrated mouse connector)	Main IRSP control station Host platform for the SCS Controls/communicates with all other IRSP equipment via PCI cards (see below)
PCI Ultra Wide SCSI card	Standard PCI card	Controls SCSI data storage devices
PCI Frame Grabber card	Standard PCI card	Capture digital imagery for NUC
PCI 1553 Interface card	Standard PCI card	Interface to the UUT 1553 bus
PCI GBIB card	Standard PCI card	Control and/or communication to other subsystem equipment
PCI Bit-3 card	Standard PCI card	Send set-up and control commands to the SBIR IRES VME control chassis
SBIR IRES VME Control Chassis	19" rack mount 21 slot VME chassis	Accepts input image data (DDO2 16-bit digital or NTSC analog format) Performs real-time NUC Provides visual display output Formats image data and timing for IRES
VME Convolver CCA	Single CCA with following daughter CCAs DD02 digital video input NTSC analog video input VGA output	Accepts input image data (DDO2 16-bit digital or NTSC analog format) Provides visual display output
VME Pixel processor CCA	Custom VME card	Performs real-time NUC using 32-point linear interpolation
VME Output controller CCA	Custom VME card	Formats data for output to the resistor array
VME Read-out integrated circuit timing CCA	Single CCA with fiber optic converter daughter CCA	Adds resistor array timing information Converts data to fiber optic signals which drive the IRES
VME Bit-3 CCA	Standard VME card	Accept set-up and control commands for the VME CCAs from the control PC
Operator Console	17" rack mount SVGA monitor	Displays operator GUI

Table 2.1-1. CES Detailed Component Listing

2.2. Software Control Subsystem (SCS)

The SCS is a Windows based GUI written in Visual C++ enabling all control of the IRSP through the local control PC or via remote Ethernet commands. The fundamentals of the SCS were designed with Microsoft's Visual Studio 6.0 Enterprise Edition. The SCS includes all necessary drivers to communicate to all the required PCI cards (e.g., Frame Grabber, 1553, Bit-3). An illustration of the main GUI screen is given in Figure 2.2-1.

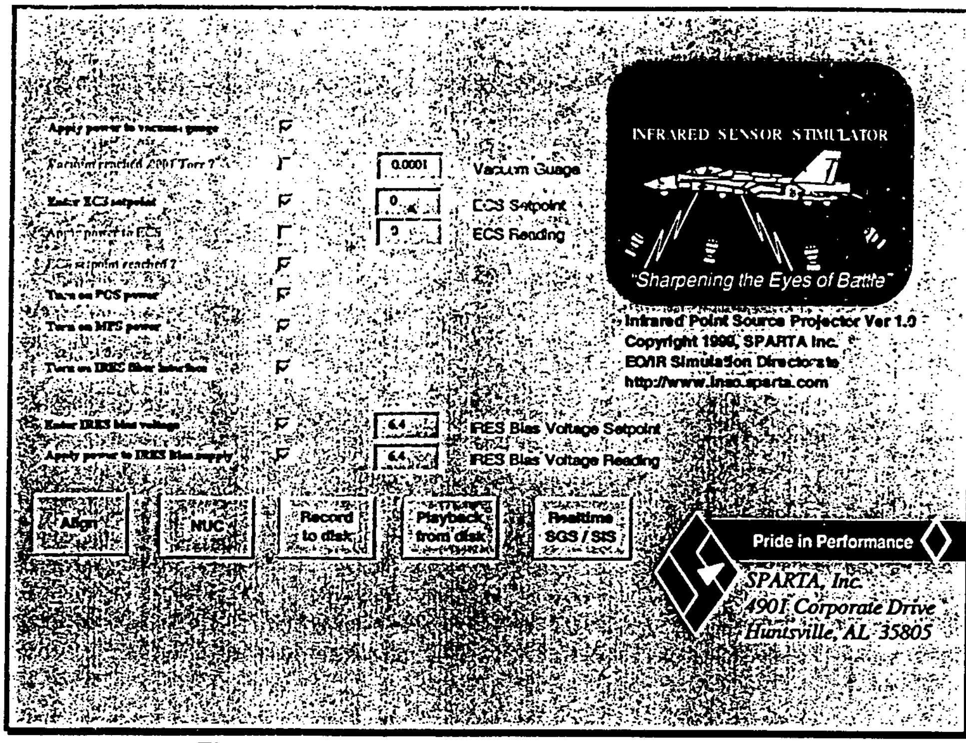

Figure 2.2-1. Illustration of SCS Main GUI Screen

2.3. Infrared Emitter Subsystem (IRES)

The IRES, illustrated in Figure 2.3-1, contains a dewar enclosed 512x512 SBIR resistor array[2,8], a compact three card close support interface CCA assembly (dual fiber-optic and power interfaces), a vacuum gauge, and remote power supplies (can be placed up to 75 feet away). The IRES is designed to physically align and mount to the POS. The resistor array is mounted on a heat sink inside the dewar behind a radiation shield and a ZnSe transmission window. The radiation shield serves the purpose of blocking all but the active area of the resistor array (blocking bonding wires, grounding strips, etc.). Prior to driving the resistor array it is required that the dewar be brought to a vacuum level of at most 10E-4 torr and then be provided with re-circulating fluid for substrate temperature control, which will typically be set to 273 Kelvin. This sequence of vacuum prior to chilling is critical to avoid condensation damage to the active resistive elements. The heat sink contains integral resistive heater elements that are used to maintain the array substrate temperature with greater precision than a re-circulating chiller can provide. These heater elements are commanded via a temperature controller in the ECS. After initial vacuum pumping, with a vacuum pumping station (part of the ECS), the dewar can be disconnected and maintain better than a 10E-4 torr vacuum level for at least 8.0 hours (expectation are for several days). There are proprietary features in the array which greatly reduces the potential for thermal cross talk or blooming when a large number of closely spaced resistors are driven to high output radiance. The power supplies are set-up and controlled by the SCS via GPIB communication from the CES. Using the IRES vacuum gauge, the dewar vacuum level is monitored by the SCS via GPIB communication from the CES.

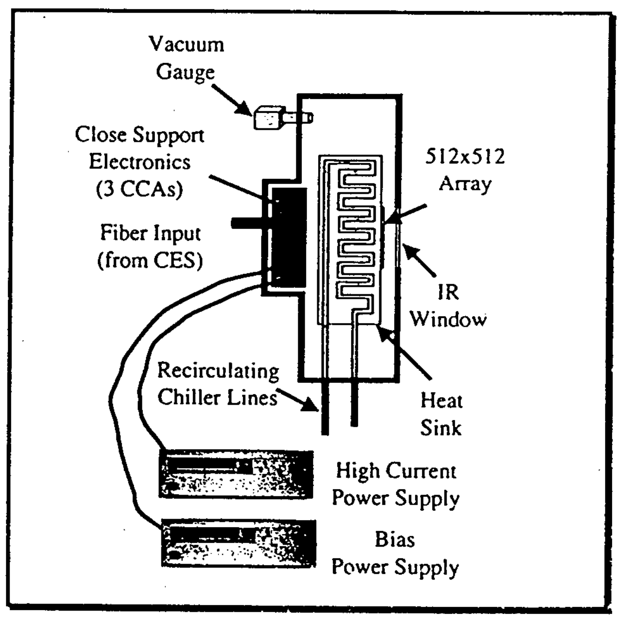

Figure 2.3-1. Illustration of IRES

The resistor array has the following additional properties:

- Spectral Band - 2-14 μm
- Resistor Pitch - 39 μm
- Fill Factor - 46%
- Spatial Resolution - 512x512 (active area of 20x20 mm)
- Effective Blackbody Temperature - 780K (3-5 μm) and 606K (8-12 μm)
- Frame Rate - 200 Hz
- Frame Update Modes - selectable between snapshot or raster scan
- Input Data Signal Format - all digital 16-bit/resistor (on chip DACs)

2.4. Environmental Control Subsystem (ECS)

The ECS, illustrated in Figure 2.4-1, encompasses a circulating chiller, a turbomolecular vacuum pumping station and a temperature controller. The circulating chiller provides the fluid to the IRES heat sink as required to maintain the array substrate temperature. The turbomolecular vacuum pumping station consists of a roughing pump, a turbomolecular pump, a vacuum gauge, and a vacuum gauge controller. It is used to bring the IRES dewar down to less than 10E-4 torr, at which point it is disconnected enabling the IRES dewar to maintain the vacuum. The temperature controller commands the IRES integral resistive heaters to maintain the substrate temperature set-point with greater precision than the chiller alone. The chiller and temperature controller is set-up and controlled by the SCS via GPIB communication from the CES. Using the ECS vacuum gauge, the vacuum level is monitored by the SCS via GPIB communication from the CES. The use of an IRES vacuum gauge and an ECS vacuum gauge protects against the potential of contaminants entering the IRES dewar and damaging the resistor array by ensuring that the vacuum pumping station is at a lower vacuum than the IRES dewar. Therefore, when the valve is opened any potential particles will be pulled out of the IRES dewar.

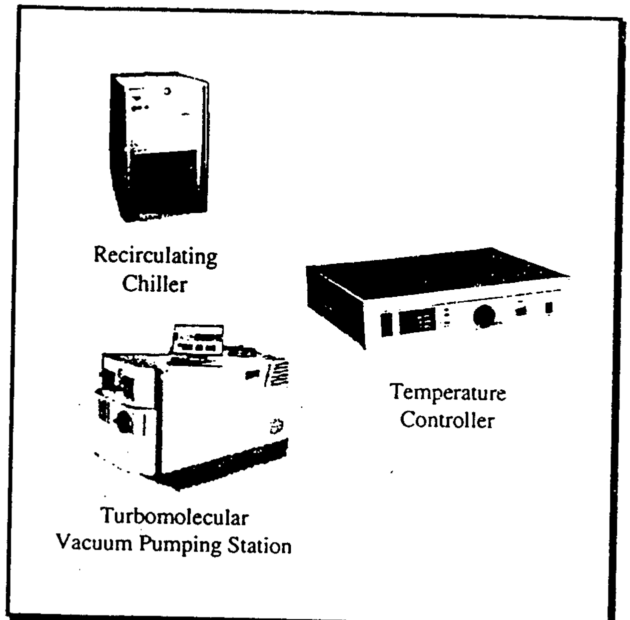

Figure 2.4-1. Illustration of ECS Components

2.5. Projection Optics Subsystem (POS)

The POS, illustrated in Figure 2.5-1, is a custom built optical assembly that enables proper projection into the UUT. The POS is designed to optically interface and physically mount to the IRES. The POS/IRES combination is designed to physically mount to the MPS, which is used to align it to the UUT. The POS is a long wave IR (8-12 μm) dual field of view (FOV) system (897 & 480 mm focal lengths) capable of switching FOVs in about 0.5 seconds. The POS has a spectral transmission of approximately 80% across the 8-12 μm wave band. To permit use of future larger resolution resistor arrays, the POS has been designed to project a 4.87° diagonal FOV when at the long focal length (897 mm) and a 19.1° diagonal FOV when at the short focal length (480 mm). In either case, the POS projects radiation from a focal plane diagonal region of 76.2 mm (approx. 54x54 sq. mm). The active 512x512 SBIR resistor array will project into a 1.28°x1.28° portion of the POS FOV at the long focal length and a 5.0°x5.0° portion of the POS FOV at the short focal length.

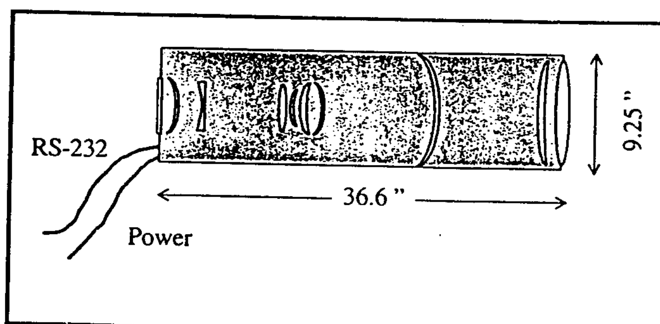

Figure 2.5-1. Illustration of POS

When properly aligned using the MPS, the POS will project collimated IRES energy uniformly overfilling the UUT entrance aperture in both UUT FOVs at a physical POS to UUT standoff distance of no more than 254 mm. The focal lengths of the POS were derived from the analysis presented in a recent publication[11]. The POS is set-up and controlled by the SCS via GPIB communication from the CES.

2.6. Mounting Platform Subsystem (MPS)

The MPS, illustrated in Figure 2.6-1, is a custom designed mounting platform that enables alignment for proper projection into the UUT. The MPS contains a wheeled base, a local equipment area, a motion stage controller, and a set of motion controlled fine positioning stages. The wheeled base of the MPS is used for gross positioning of the IRSP in front of the UUT. The local equipment area is used to house equipment such as the ECS chiller & vacuum, the NUCS sensor, the IRES power supplies, and the motion stage controller. The positioning portion of the MPS contains commercial stages in a custom configuration that provide for 5 axes of controllable motion to align the IRES/POS to the UUT. In addition, the positioning portion enables the IRES/POS to be manually rotated approximately 180° for projection into the NUCS sensor. The reference point of the controllable motion is the intersection of the optical axis of the POS (nominally at 47 inches above the floor) and the exit pupil of the POS (a plane 254 mm in front of the POS perpendicular to the POS optical axis). The MPS provides for the following motion ranges about the reference point, controlled by the SCS via GPIB communication from the CES:

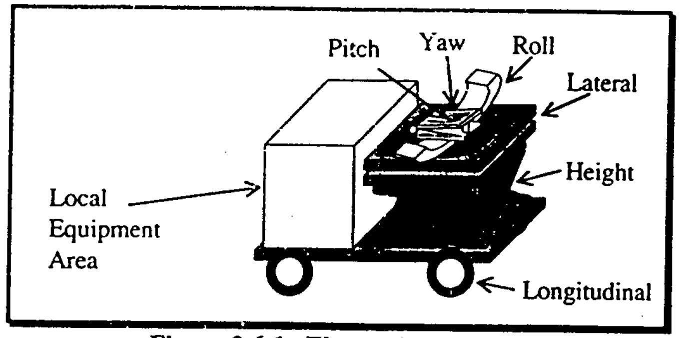

Figure 2.6-1. Illustration of MPS

- Lateral (X axis) - ± 3.0 inches
- Height (Y axis) - ± 6.0 inches
- Pitch (rotation about the X axis) - ± 5.0 degrees
- Yaw (rotation about the Y axis) - ± 5.0 degrees
- Roll (rotation about Z axis) - ± 2.0 degrees

NOTE: The longitudinal (Z axis) is controlled by wheeling the MPS in front of the UUT.

2.7. Non-Uniformity Correction Subsystem (NUCS)

The NUCS, illustrated in Figure 2.7-1, is a custom configured subsystem designed to correct for the material property non-uniformity inherent in the resistor array. The NUCS consists of an 8-12 μm imaging radiometer, a custom camera to frame grabber digital data signal converter, and all associated control & processing software. The NUCS imaging radiometer has selectable FOVs of 1.5°x2.0° and a 5.0°x7.0° (vertical by horizontal). A full description of the hardware used for this purpose can be found in a previous publication[9]. In short, the hardware is functionally used to capture radiometric imagery of the IRSP for data analysis and processing. Prior to explaining the NUC process, it helps to define a few parameters. The first, "the sparse resistor pattern", is defined as a pattern in which only every Nth horizontal and Mth vertical resistor is commanded to the same value (every other resistor is commanded to 0). The second, "input level", is defined as the commanded input which in our case is some digital value between 0 - 2^{16}. With these definitions in mind, the process for sparse array non-uniformity correction used for the IRSP is as follows:

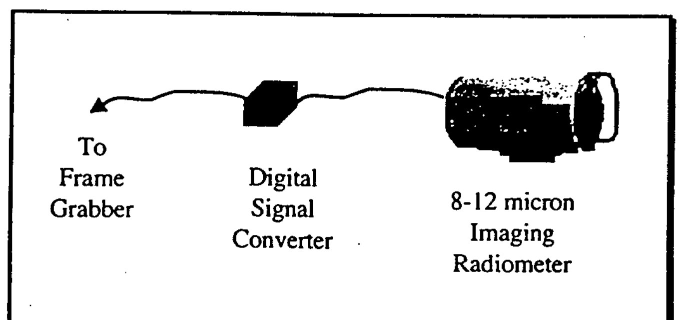

Figure 2.7-1. Illustration of NUCS Components

- STEP 1 – Determine Data Acquisition Parameters

  There are a number of user controllable data acquisition parameters that must be determined prior to performing NUC. First, select the POS and NUCS sensor FOV (the default is to use both narrow FOVs). Second, select the region of the resistor array for which NUC is to be performed (the default is the entire array starting at row=0, col=0). Third, select the sparse resistor horizontal and vertical spacing (the default is 10 x 10). Fourth, select the number and values of the commanded input levels (the default is 32 equally spaced input drive commands spanning the maximum input to the minimum detectable single resistor input). Finally, select the number of frames to average for noise reduction (the default is 32).
- STEP 2 – Align the NUCS Sensor to the IRSP

  The NUCS sensor is treated as another UUT for alignment. The MPS is used to position the POS/IRES combination such that the POS's exit pupil overfill the NUCS sensor with uniform radiation. A variety of alignment patterns can be used for this purpose. Depending on the selected POS FOV, NUCS sensor FOV and resistor array area of interest, it may be necessary to realign to the NUCS sensor and repeat the below process several times. For example, in the POS wide field of view the resistor array projects across a 5.0°x5.0° region. Thus, even when using the NUCS sensor wide FOV to NUC all the resistors, the below process must be followed at least twice to account for optical distortion effects. The user has the ability to align and store the required number of alignment positions. Using the default POS and NUCS sensor narrow fields of view, there is only one alignment required to NUC the entire array.
- STEP 3 – Generate, Project, Capture and Calculate a Distortion Map Pattern

  To perform NUC one must be able to isolate the location of each resistor as seen by the NUCS sensor. A pure geometric mapping of the resistors is typically not accurate enough due primarily to optical distortions in the POS and NUCS sensor. Due to these distortion effects, it is necessary to define a resistor to detector distortion map using an alignment pattern. The alignment pattern used consists of commanding resistors in known locations at 25 (row, col) positions evenly distributed throughout the array. Since some resistors may be dead or low performers, it is not practical to only command single resistors. Instead, groups of 5x5 resistors are commanded and their local centroids are used to generate the distortion map. The distortion map is simply a set of two dimensional least squares curve fits, one each for the actual NUCS sensor row and column locations of a given resistor. It is anticipated that using zero order, linear, and quadratic terms will be sufficient to calculate an adequate resistor to NUCS sensor distortion map. A new distortion map is calculated for each shift in the sparse pixel pattern to account for potential alignment drift.
- STEP 4 – Define the Current Sparse Pixel Pattern (first cycle start at row=0, col=0)

  Given the sparse resistor spacing defined in STEP 1, the sparse resistor pattern is defined. For example, the first cycle starts at row=0 and column=0. Using the default of 10x10 spacing, resistors 0,10, ..., 510 at rows 0, 10, ..., 510 are defined as "ON" pixels.
- STEP 5 – Generate, Project, and Capture the Commanded Input Level (first cycle at max input level)

  This step is used to cycle through the commanded input levels defined in STEP 1. Each "ON" pixel determined in STEP 4 is commanded to the current input level. The frame grabber is then used to capture the selected number of frames defined in STEP 1.
- STEP 6 – Process the Captured Image; Determine and Store the Output of Each Commanded Sparse Resistor

  Physical limitations (e.g., aberrations and diffraction) of the POS and NUCS sensor optics will cause the energy from a resistor to be incident on a local region of detector samples extending significantly beyond what geometric optics would predict. This is the fundamental reason to separate the resistors in a sparse pattern. Using the distortion map generated in STEP 3, an extended local region is defined centered on each commanded resistor (typically a 9x9 group of detector samples). This extended region contains the local region of resistor radiation and some of the local background. To account for NUCS sensor noise and responsivity variations, the median of the background region is subtracted from a normalized accumulation of a small centered region about the commanded resistor (typically 5x5 detector samples). This quantity is not a radiometric quantity, but rather simply describes the relative delta output signal above the localized background for each commanded resistor. It is stored for each resistor as a function of commanded input level.
- STEP 7 – Select the Next Input Level and Repeat STEPs 5 & 6, if Finished go to STEP 8
- STEP 8 – Select the Next Sparse Resistor Column and Repeat STEPs 3 - 7, if Finished go to STEP 9
- STEP 9 – Select the Next Sparse Resistor Row and Repeat STEPs 3 - 8, if Finished go to STEP 10
- STEP 10 – Create and Store NUC Curve Coefficients for Each of the 262,144 Resistors

STEP 6 provides data points that describe the resistor output as a function of known commanded input level. However, what we want is to provide the desired output (i.e., the value coming from the scene generator) and calculate the required resistor input level to achieve it. One might believe that it should be theoretically possible to simply fit a least squares curve to the data. Unfortunately, due to NUCS sensor noise, as well as, dead or low output resistors, it is necessary to not only interpolate between data points, but also extrapolate to cover the desired radiometric output range. This desired range typically extending from a state of the resistor being "OFF" to some predetermined maximum output level. Through trial and error on data collected from similar resistors[4], the best resulting curve fits were found by:

(a) fitting a linear least squares 7th order polynomial curve representing resistor output as a function of commanded input level,
(b) use the polynomial data of (a) from the highest 1/4 commanded input levels to extrapolate the high output end with a linear least squares 1st order logarithmic fit,
(c) use the polynomial data of (a) from the central 1/2 commanded input levels to extrapolate the low output end with a linear least squares 1st order logarithmic fit,
(d) use the data from (a), (b), and (c) above to fit a linear least squares combined 3rd order logarithmic and 2nd order polynomial curve relating resistor output as a function of the commanded input level.

- STEP 11 – Calibrate the NUC Curves

  Since STEPs 6 & 10 dealt with relative delta output signal above the localized background and not true radiometric quantities, it is still necessary to calibrate the resistor curves. The results of STEP 10 are used to command contiguous large groups of resistors to the same output (typically 20x20 resistors). To the NUCS sensor this appears as one large extended source. Since the NUCS sensor is a calibrated radiometer, it is now possible to calculate a radiometric calibration curve relating in-band effective blackbody temperature (or radiance) to the relative delta output signal above the localized background. At this step, any known fixed POS transmission effects can also be taken into account. The NUC curve coefficients generated in STEP 10 are modified to incorporate this calibration step.
- STEP 12 – Calculate 32 Point Linear Interpolation Tables for Real-Time NUC

  Since STEP 11 produces analytical functions representing the input/output relationship of each resistor (via curve fit coefficients), it is a trivial task to create the 32 point look-up tables needed to implement NUC in real-time in the CES.

A similar, but alternative procedure is available in a companion paper[1].

3. UNIT UNDER TEST (UUT) STIMULATION

There are multiple variations in the angular, temporal, spectral, and radiometric requirements on an IR stimulator to support all of the potential UUTs (e.g., FLIR, IRST, MWS, missile seekers). It is not practical to expect an IRSP to have a single configuration capable of supporting all possible UUTs. Instead, as described earlier, the IRSP has been designed in a modular configuration that enables it to be configured for the present UUT application. Below each of the potential UUTs is briefly described along with some typical high-level stimulation requirements. Emphasis here is place on the FLIR since it is the first system designated for use, design consideration and/or implementation techniques are also provide for the other potential UUTs.

3.1. Forward Looking Infrared (FLIR)

FLIRs are typically a broadband mechanically scanning imaging device operating at video frame/field rates (30 to 60 Hz) providing a high degree of image resolution while viewing targets at long ranges with extremely low delta temperatures. FLIRs generate an image for the user to view in an attempt to characterize a potential target of opportunity (i.e., detect, recognize, classify, or identify). Initially, FLIRs have been highly dependent on a human in the loop. There currently exists limited image processing functions that enable some FLIRs to track targets designated by a trained user, or in some cases, autonomously detected potential targets of opportunity. In future designs, improved image processing algorithms will provide more advanced aided/automatic target characterization functions.

Some FLIRs are gimbal mounted and are capable of pointing in a direction different from the host platform line-of-sight, thereby giving them a field of regard that exceeds the sensor FOV. The gimbal drive mechanism must be disabled to permit the IRSP to maintain optical alignment with the FLIR for simulation scenarios that require relative motion of the FLIR from the host platform (e.g., as a helicopter banks right and the FLIR maintains lock on a ground target). Disabling the gimbal may require a gimbal emulator to enable the host platform to still function properly.

These types of scenarios do not impede the ability of the IRSP to stimulate the FLIR, but rather require a more sophisticated simulation process capable of controlling other stimulators or as in this case emulators. The issues and requirements associated with bypassing host platform sensor components are further described in a companion paper[5]. The design of this IRSP assumes a fixed alignment between the FLIR and IRSP.

Ideally, one would like to provide an IRSP image resolution exceeding the UUT's image resolution. Some have suggested over-sampling ratios of 2x2:1 (resistors to detector samples)[12]. However, because of the high image resolution of a FLIR sensor, there exists a "dog chasing its own tail" problem. The technologies required to manufacture the resistor arrays leverage heavily from the technologies required to manufacture the IR sensors. As IR sensors increase in resolution, the resistor arrays seem to always be playing catch-up. This problem forces the IRSP designer to make a trade-off between filling the FLIRs FOV or providing high image resolution over some restricted sub-FOV. The decision needs to weigh heavily on what is the planned utilization of the IRSP. Is the spatial frequency information more important than filling the UUT's FOV? The design for the subject IRSP system used an analysis that emphasizes maintaining spatial frequency information[11]. Therefore, this IRSP design resulted in a system capable of projecting into a sub-FOV of the UUT leaving room for upgrading to higher resolution resistor arrays as they become available.

It is essential that the IRSP provide flickerless imagery to the UUT to accommodate a mechanically scanning imaging device. This is a fundamental design characteristic of a resistor based projector. Any attempt to stimulate such a system with a mechanically scanning projector (e.g., a scanning laser diode array projector) is almost sure to fail. This restriction is removed for UUTs with staring focal plane arrays.

The projector should be able to update and settle to the commanded scene at a rate compatible with the UUTs field/frame rate. Micro-resistors have extremely low thermal mass thereby enabling the 512x512 arrays to be driven at frame rates on the order of 120-200 Hz. with 10-90 percent rise and fall times on the order of a few milliseconds.

It is not practical to expect a resistor array to be capable of generating effective blackbody temperatures that span the entire operational envelope of the UUT. Instead, restrictions are placed on the types of valid scenarios that can be stimulated. Fortunately, for the FLIR to be capable of high radiometric resolution for long range low delta temperature targets, it will usually saturate below the output capabilities of a resistor array based IRSP (several hundred degrees Celsius). However, validation limitations are necessary for the low-end background radiation, which is typically limited by the IRES cooling and the surrounding thermal environment.

3.2. Infrared Search and Track (IRST)

An IRST usually encompasses a single element or linear array of detectors, which are used to build thin strip like images (called bars) within the sensors extremely large Field Of Regard (FOR). An IRST typically operates in an autonomous mode performing search patterns, which can change in regards to selected targets. This configuration varies dramatically from a scanning FLIR. In the case of the scanning FLIR (with or without a gimbal), there is an internal mirror which 'paints' the sensors FOV across the linear array or single element detector. In the case of the IRST, the gimbal is the mechanism that 'paints' the sensors current FOV (or bar) across the detector(s). This enables the IRST to build extremely high-resolution images in the direction of the scan (2000 pixels or more). A FLIR system can be configured to operate as an IRST by locking the internal scan mirror in place and using the gimbals, however this is the exception.

For an IRST, or a FLIR, operating in an IRST mode, it is not appropriate to disable the gimbal for resistor array based scene projection. Doing this would force the IRST detectors to always be aligned with the same resistors. The problem lies in the fact that a single detector's integration time is on the order of a few microseconds, much faster than a resistor can settle to the commanded change. As an example valid stimulation configuration, one could permit the IRST to perform its scan pattern and project imagery only in a limited angular region of the IRST FOR. As the IRST detects potential targets coming from the IRSP, the IRST would autonomously adjust its scan pattern and slew to the projected target. For this to work all outside sources of radiation would have to be shielded from the IRST.

3.3. IR Missile Warning System (MWS)

An IR MWS represents a variety of sensor systems designed to detect, declare, track and react in some way to an incoming missile threat(s). A subset of this category of UUTs is a Missile Launch Detector (MLD). On an airborne platform, missile threats can come from any direction, requiring a full 4π steradians MWS FOR. This is typically accomplished using multiple sensors with staring focal plane arrays, each with extremely large overlapping FOVs. Successful evaluation of the MWS, depends on processing algorithms which must handle target cross-over from one sensor FOV to another. To stimulate such a system requires at least two (2) IRSPs projecting into adjacent sensor systems. The technical challenges lie in the need for extreme FOV projection optics and in mounting interface & alignment issues.

3.5. IR Missile Seeker

Imaging IR missile seekers typically have a relatively low resolution staring detector focal plane array. Historically, almost all IRSPs have been designed for stimulating IR missile seekers. The high-fidelity flight dynamics of the missile seeker is typically accounted for in the scene generation and in the control of complex mechanical 5-axis flight motion tables. Configuring the IRSP for this kind of stimulation requires mounting on the motion table and designing optics to match the specific UUT parameters. As with all other UUTs discussed above, the validity of the stimulation will be governed by the radiometric output and temporal response properties of the IRSP. For the most part, resistor array based IRSPs are very well suited for IR missile seeker stimulation.

4. SIMULTANEOUS RF/IR STIMULATION REQUIREMENTS

At the writing of this paper the operational concept/implementation of the IRSP in a RF test chamber is in the initial design phase. Figure 4-1 illustrates how the subsystems and subsystem components would be distributed. Most close support components would be located under the chamber floor in nearby equipment rooms. The CES will be located remotely up to 1 kilometer away. The RF chamber facilities at the ACETEF and ATIC are further described in a companion paper[3]. The overarching requirement for the IRSP is to have as few hardware components in the chamber as possible to avoid potential RF interference. The current IRSP design lends itself to such a configuration, requiring only the IRES dewar, POS, and MPS to be in the chamber with a cumulative mass of as little as 50lbs. The MPS for a chamber configuration should provide whatever RF shielding is necessary; as well as, the alignment interface to the UUT. The current MPS conceptual design incorporates radar absorbing material around all IRSP chamber equipment.

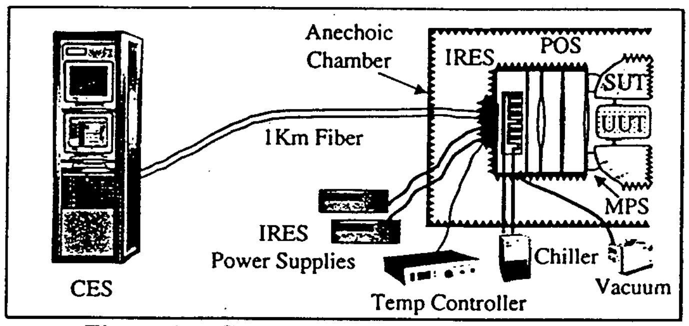

Figure 4-1. Conceptual Chamber Configuration

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